HUMBER RIVER

BACTERIA SOURCES AND PATHWAYS STUDY

TECHNICAL REPORT #13

A REPORT

OF THE

TORONTO AREA WATERSHED
MANAGEMENT STRATEGY
STEERING COMMITTEE

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TORONTO AREA WATERSHED MANAGEMENT STRATEGY STEERING COMMITTEE MEMBER AGENCIES

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ABSTRACT

Because bacterial pollution of various watercourses in the Metropolitan Toronto area resulted in the closure of many recreational beaches, the River Systems Assessment Unit initiated the Humber River - Bacteria Sources and Pathways project in October 1984. The objective of the project was to develop a control strategy to reduce instream bacterial levels and loadings in the urbanized Humber River watershed as part of the Toronto Area Watershed Management Strategy (TAWMS) Study.

The study entailed compiling and evaluating available data on fecal coliform bacteria in the urbanized Humber River. A first-order systems model, incorporating die-off, was developed and calibrated to existing conditions. This model was then applied to assess the impacts on the instream fecal coliform levels due to the simulated implementation of proposed control options.

Conclusions resulted in the development of a multiple-phase control strategy to reduce instream fecal coliform guideline violations and to reduce event bacterial loadings to the lakefront. Recommendations, as described in the Humber River Water Quality Management Plan, detail the various control option implementation stages.

RÉSUMÉ

La pollution bactérienne de divers cours d'eau de l'agglomération torontoise ayant conduit à la fermeture de plusieurs plages publiques, l'Unité de l'évaluation des réseaux fluviaux a lancé le Projet d'étude des sources et des voies d'entrée des bactéries de la rivière Humber en octobre 1984. Ce projet vise à mettre sur pied une stratégie de dépollution visant à la réduction des charges et des concentrations bactériennes dans la partie urbanisée du bassin de la rivière Humber, dans le cadre de l'étude sur la Stratégie de gestion des bassins versants de la région torontoise (TAWMS).

L'étude a entraîné la compilation et l'évaluation des données disponibles sur les bactéries coliformes fécales dans la partie urbanisée du bassin de la rivière Humber. Un modèle primaire de systèmes, tenant compte du dépérissement, a été développé et étalonné suivant les conditions existantes. Ce modèle a ensuite servi à évaluer les répercussions, sur les concentrations de coliformes fécaux, de la mise en oeuvre simulée des options de dépollution proposées.

Les conclusions ont conduit à l'élaboration d'une stratégie de dépollution en plusieurs phases visant à limiter les infractions aux directives concernant la teneur en coliformes fécaux et à réduire les charges bactériennes résultantes sur le littoral du lac. Les recommandations, énumérées dans le Plan de gestion de la qualité de l'eau de la rivière Humber, précisent les divers stades de mise en oeuvre des options de dépollution.

ACKNOWLEDGEMENTS

The author would like to thank Messrs. D. G. Weatherbe, Z. Novak, D. Andrews, M. Young and Ms. E. Harris for the appreciated guidance and assistance received while this study was ongoing. The author is also grateful to Messrs. A. Bacchus and J. Eddie for their sampling assistance.

1.0 INTRODUCTION

Water used for recreational purposes should be sufficiently free from pathogenic microorganisms, fecal contamination and other hazards to ensure that there is negligible risk to the health and safety of the user. Recreational water refers to those natural waters used primarily for swimming and other water contact sports. Inherent in this definition are such activities as boating, fishing and other sports involving less frequent body contact with water. Recreational use represents any activity involving intentional immersion of the body, including the head, in water or where such immersion is likely (e.g. water skiing, wind surfing). Waters where inadequately treated sewage and fecal matter are present pose a potential health hazard for its' users since these substances are a primary source of disease causing organisms. Since pathogens are difficult to quantify and may only be present sporadically, the most widely accepted indicator of fecal contamination from human and animal sources, is Fecal Coliforms (FC).

In areas where natural water quality has been degraded below established objectives, as in the Humber River, field investigations should attempt to identify sources of fecal pollution that could impinge on the recreational use of water, through sanitary surveys and appropriate laboratory analyses. Sanitary surveys, directed towards quantifying the magnitude of fecal pollution, will make use of the FC test to approximate the level of pollution. However, the fecal coliform test cannot differentiate between animal and human fecal pollution due to the presence of fecal coliforms in virtually all warm-blooded animals. Another problem with the fecal coliform test is that it enumerates the species Klebsiella which is not restricted to fecal sources. Numerous studies have demonstrated the ability of Klebsiella to survive and replicate in organic-rich environments, including waters receiving effluents from pulp and paper and textile industries. This inconvenience is somewhat tempered by the fact that Klebsiella pneumoniae is considered pathogenic for debilitated hosts. Whether these are of fecal origin or not then becomes less significant in view of the potential health hazard that exists.

Guidelines deal mainly with health hazards related to recreational water uses but also relate to aesthetics and nuisance conditions. In order to provide rational microbiolgical guidelines for recreational water, it is necessary to establish some degree of health risk associated with a certain level of contamination. Microbiological surveys give valuable information for the assessment of this risk. When fecal colifom concentrations in a recreationally-used area approach 100/100 mL the possibility of other pathogenic organisms being present increases. A health hazard is considered to exist if the fecal coliform geometric mean density for a series of samples exceeds 100/100 mL.

A need for a bacteriological study in the Humber River basin arose in order to aid in the identification of the sources of bacterial pollution, which has resulted in the closure of many recreational beaches during the summer period and to assess the risk to users.

2.0 STUDY AREA

The Humber River drains an approximate watershed area of 897 km^2, as indicated in Figure 2.1. The watershed area is bounded on the east by the Don River and on the west by Mimico Creek. Parts of the watershed lie within the individual municipalities of Caledon, Brampton, Mississauga, King, Vaughan, North York, York, Etobicoke and the City of Toronto. The river flows in a south to south-easterly direction and empties into Humber Bay at Lakeshore Boulevard just west of the South Kingsway.

The upper Humber sub-watershed (north of Steeles Avenue) embodies a predominately rural area whereas the Black Creek and lower Humber sub-watersheds embody a heavily urbanized area. The rural area is approximately 3% developed while the area contained by the Black Creek and Lower Humber sub-watersheds is approximately 70% developed. On average, the developed area in the entire watershed is expected to increase from 18% in 1983 to 22% by 2000 due to a shift in land use from pasture and field crops primarily to rural residential along with some residential/commercial and industrial/commercial.

The area of concentration for this study comprised only the Humber River watershed within the Metropolitan Toronto boundaries. Specificaly this involves the urbanized area bounded on the west by the Mimico Creek watershed, on the north by Steeles Avenue, on the east by the Don River watershed and on the south by the lakefront.

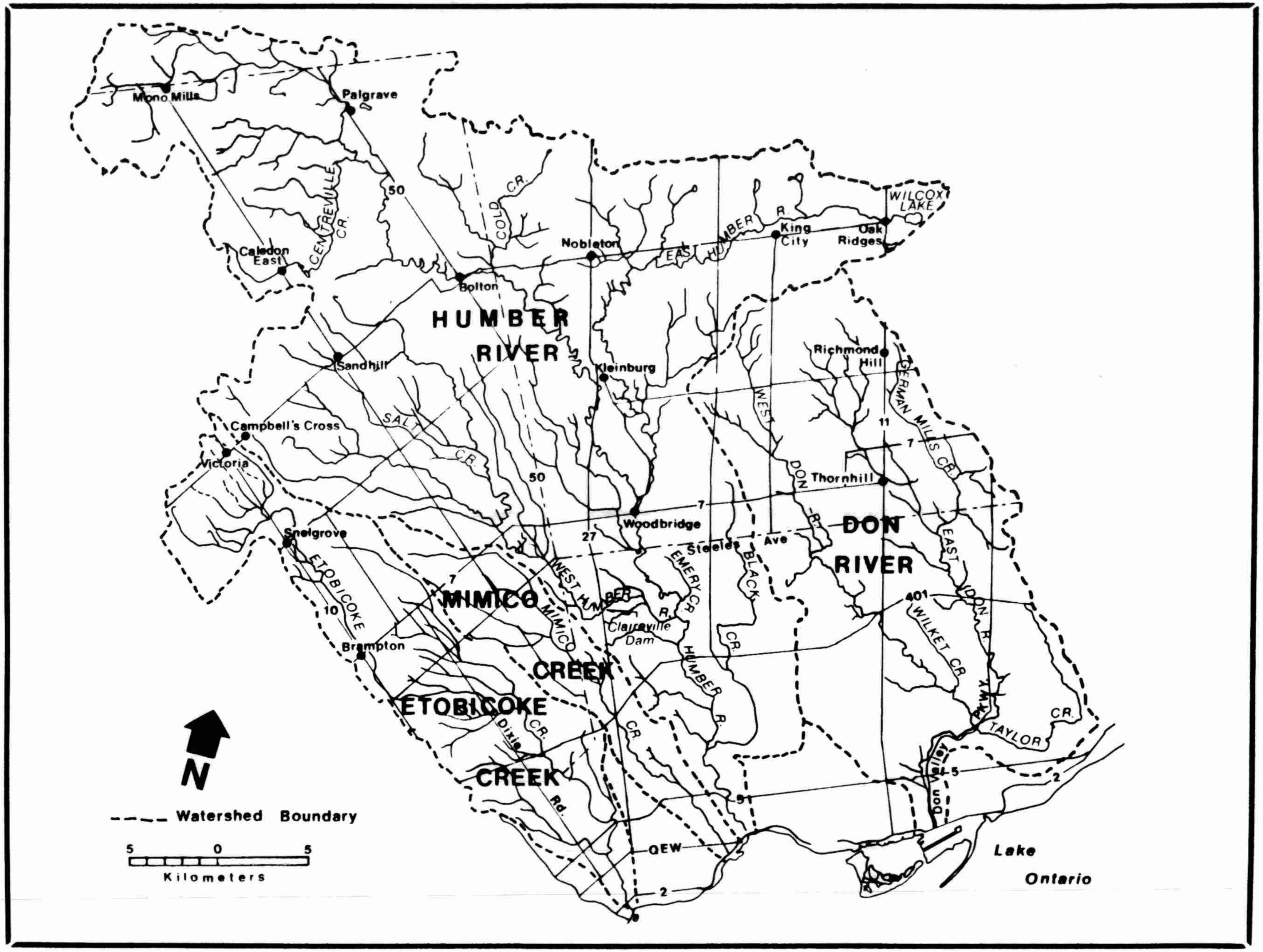


FIGURE 2.1 LOCATION OF STUDY WATERSHED

3.0 MODELLING THEORETICS

A mass balance approach, incorporating die-off, was applied to assess bacterial contamination within the Humber River watershed. The instream bacterial die-off process can be described by the first-order decay equation:

$$c = c_0 e^{-Kt} \qquad (1)$$

where: c_0 = bacterial density at the head of a segment (/100 mL)
c = bacterial density at the downstream end of the segment (/100 mL)
t = time of travel (hours)
K = die-off coefficient (hours^{-1})

Fecal coliform association with suspended particles and bottom sediments is important in the evaluation of the sedimentation component of the overall fecal coliform die-off rate. To describe declining bacterial densities, the term "disappearance" may be more appropriate. This term describes the observed phenomenon (which include sedimentation, predation, dilution and death) without implying that any one factor (such as death) is wholly responsible.

A rapid decline in fecal coliform densities in the water column is generally assumed to imply a high die-off rate. It is more probable that bacterial populations in the river sediments have been augmented, potentially harbouring sufficient numbers of pathogens to create a health hazard to body contact users via resuspension.

Presently the disappearance rates of bacteria found in the Humber River and Black Creek are unknown. A study is underway at the University of Toronto to determine the disappearance rates of fecal coliform, fecal streptococcus, E. coli, and P. aeruginosa in various reaches of the watercourses. However, for the purpose of this study, which was to assess the cause-and-effect relationship of fecal coliform transport in the watercourses, a disappearance rate of 90% fecal coliform reduction in 24 hours was assumed.

The watercourses were divided into a number of reaches as indicated in Figure 3.1. To more accurately account for the various outfall inputs within the urban areas below Steeles Avenue, each reach was sub-divided into a number of segments separated by node points. These node points are indicated in Figure 3.2. Outfalls nearest to a node were grouped as indicated in Figure 3.3. At any one node, outfall discharges and the in-stream background flow were assumed to be completely mixed. The resulting discharge and bacterial density were computed using the relationships:

$$Q_d = Q_u + \sum q_i \qquad (2)$$

and

$$c_d = \frac{Q_u c_u + \sum(q_i c_i)}{Q_d} \qquad (3)$$

where: Q_u = background (upstream) discharge at a node (m^3/s)

q_i = discharge from outfall 'i', entering the stream at the node (m^3/s)

Q_d = discharge just below the node (m^3/s)

c_u = background bacterial density (/100 mL)

c_i = bacterial density from outfall 'i' (/100 mL)

c_d = bacterial density just below the node (/100 mL)

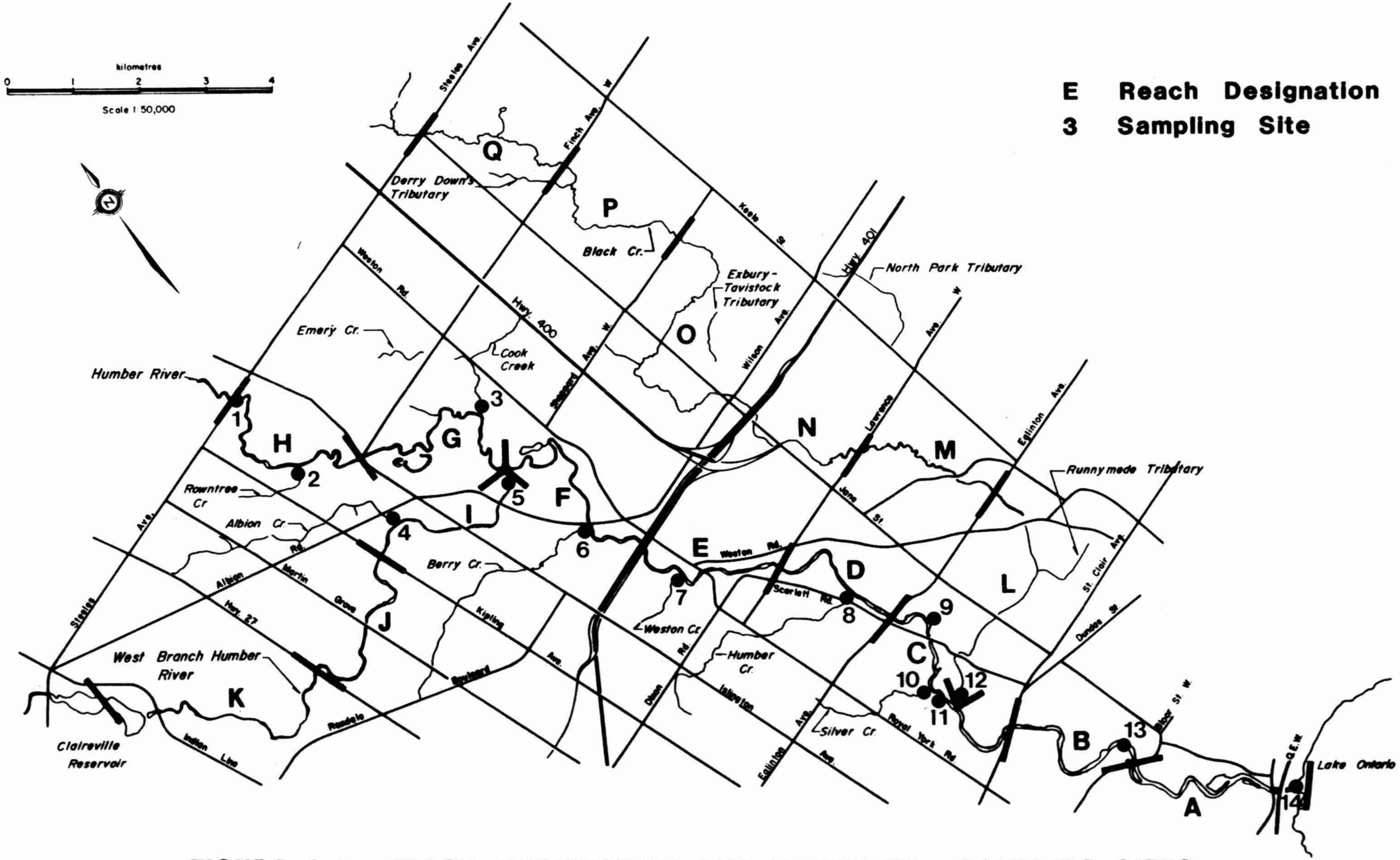
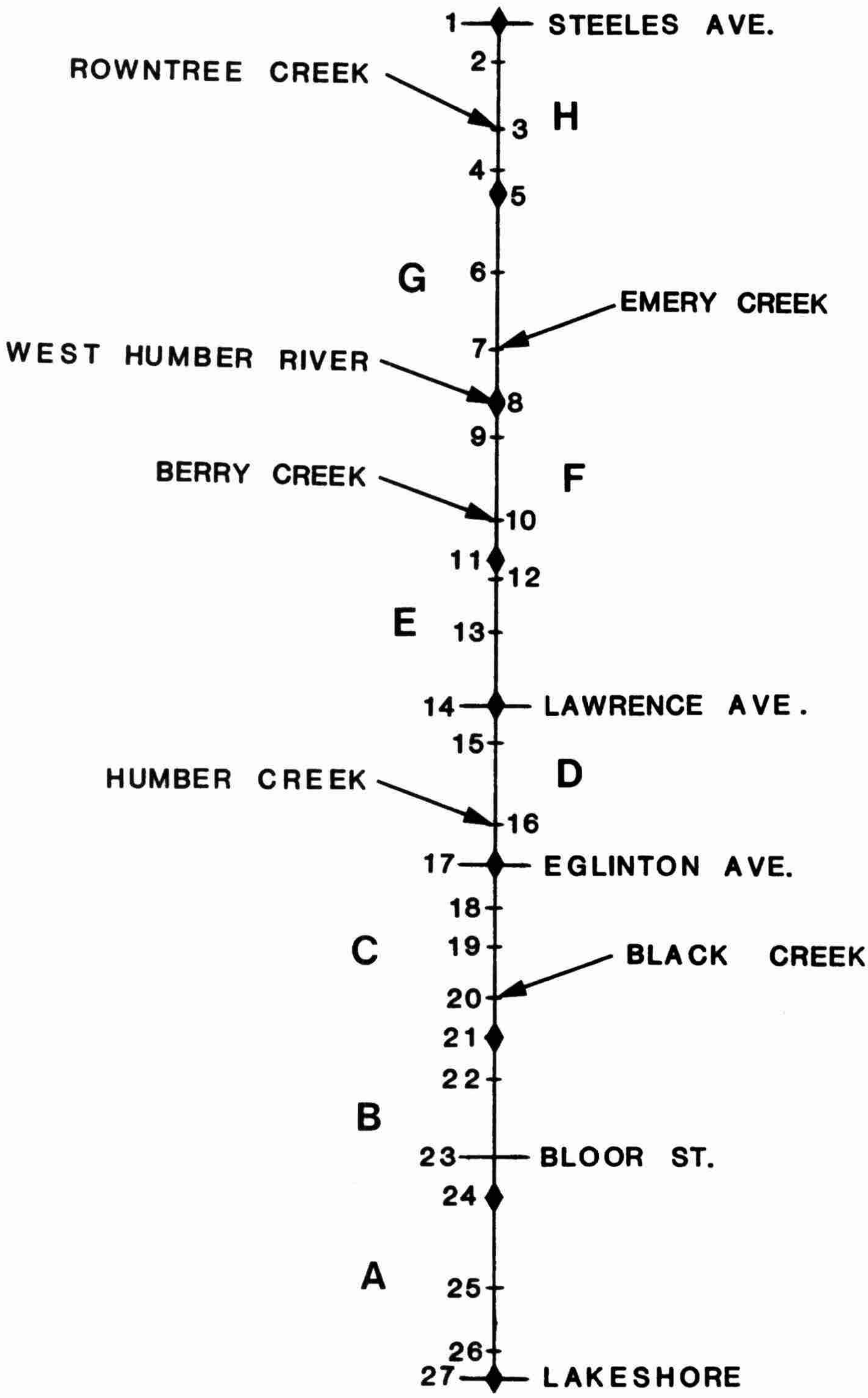


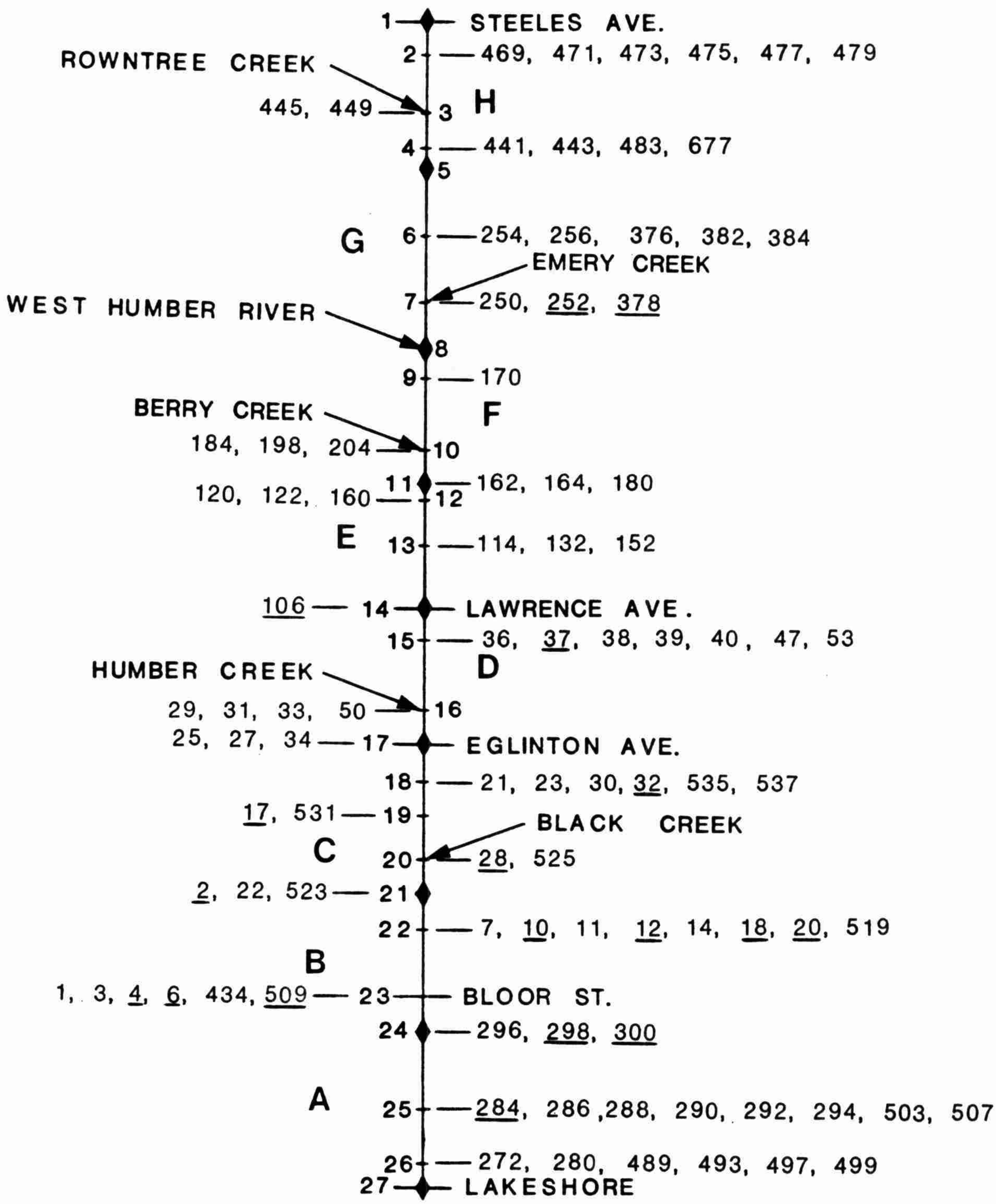
FIGURE 3.1 REACH DESIGNATION AND TRIBUTARY SAMPLING SITES

FIGURE 3.2 NODE DESIGNATION



♦ **Reach Boundary**
B **Reach Name**
4 **Node No.**

FIGURE 3.3 OUTFALL GROUPING



♦ **Reach Boundary**
B **Reach Name**
4 **Node No.**
25, 27, 38 **Outfall Grouping**
<u>252</u> **Priority Outfall**

The time of travel through each segment was calculated from the relationship:

$$t = laQ^{-b} \qquad (4)$$

where: t = time of travel (hours)

l = fractional segment length (dimensionless)

Q = discharge (m^3/s)

a = empirical constant

b = empirical constant

The values of a and b were determined for each reach in the summer of 1982 and are summarized in Table 3.1.

The computer software package Lotus 1-2-3 was set up to perform the computations as per equations 1-4. Simulations were initiated by inputting known flows and background fecal coliform densities at node 1 (Humber River at Steeles Avenue).

To give an overall representative view of in-stream bacterial response, dry and wet weather events were modelled separately due to differences in hydrologic conditions. Specific events were selected and modelled to represent typical summer dry weather and wet weather conditions. Humber River water samples were taken at Steeles Avenue, the Old Mill Bridge and at Lakeshore Boulevard for calibration of extreme dry weather conditions. Unfortunately, the number of observations were small making statistical testing of simulated data difficult. Calibration of the wet weather event was not possible due to the lack of available data. However, the model was still considered useful on a relative basis to compare the impacts of each wet weather control option scenario.

Table 3.1

DATA FOR TIME OF TRAVEL COMPUTATION

STREAM	LOCATION	REACH	a	b
Humber River	Steeles Ave. to West Humber River Confluence	H & G	8.8233	0.3970
Humber River	West Humber River to Lawrence Ave.	F & E	11.708	0.5550
Humber River	Lawrence Ave. to Scarlet Rd.	D & C/4	4.845	0.6230
Humber River	Scarlet Rd. to Bloor St.	3C/4 & B	9.612	0.5118
Humber River	Bloor St. to Lakeshore Blvd.	A	4.806*	0.3500

* One-half of the value in the previous reach.

4.0 DRY WEATHER ANALYSIS

4.1 Data Set and Model Calibration

Each active dry weather outfall was identified and sampled by Gartner-Lee in the fall of 1982. Average discharges and geometric mean fecal coliform densities were assumed constant and representative of the existing situation. Recent sampling results, as of July 1985 (TAWMS, Abatement Committee), were used to update the geometric mean fecal coliform density of priority outfalls. Using the mass balance approach, described in the previous section, fecal coliform densities were calculated for each node.

It should be noted that this modelling exercise is similar to the Gore & Storrie bacterial modelling described in the TAWMS Technical Report #6. However, to allow for a more realistic presentation of the situation in the tributaries, a sanitary survey was carried out in the summer of 1985 to supplement available data. Flow was measured and water quality samples were taken at the mouth of certain tributaries indicated in Figure 3.1. These flows and respective fecal coliform counts were used as input into the model instead of the flow and bacterial quality, as measured by Gartner Lee, from individual outfalls discharging to the tributary. Any bacterial die-off and sedimentation occurring in the tributary was then accounted for. Figure 3.3 schematically details the outfall groupings and tributary inputs within the watershed.

Simulated results were compared to the actual counts observed on July 25, 1985 as indicated in Table 4.1. Although the simulated value at Lakeshore Boulevard was slightly smaller than the observed value, it compared well with the geometric mean calculated from a larger data set. This discrepancy may be due to the onshore wind noted on the day of sampling, which may mix lake water with Humber River water.

As with the Lakeshore value, the simulated value at the Old Mill Bridge compared well with the geometric mean calculated from a larger data set. The simulated value, on the other hand, was greater than the value observed on July 25. The standard deviation however, indicates a sensitivity in the area. This sensitivity may be due to the assumption of continuous dry weather flow from priority sewers. Many storm sewers discharging directly to the Humber River in the Old Mill area possess extremely high fecal coliform concentrations. If their respective flows and concentrations are not continuous as assumed, the load to the Humber River as simulated is artificially high. Also, the estuary effect between Lake Ontario and the Humber River has been noted as ending at the Old Mill Bridge. However, how this relationship affects bacterial counts has not been studied.

The model remains useful on a relative basis although more sanitary surveys would be required to accurately calibrate the dry weather model.

Table 4.1 - Actual vs Simulated Dry Weather FC Results

	Lakeshore	Old Mill
	(FC counts/100 mL)	
Geometric Mean	839*	979**
Standard Deviation	1330	2669
Simulated Value	923	1027
Observed - July 25, 1985	1200	440

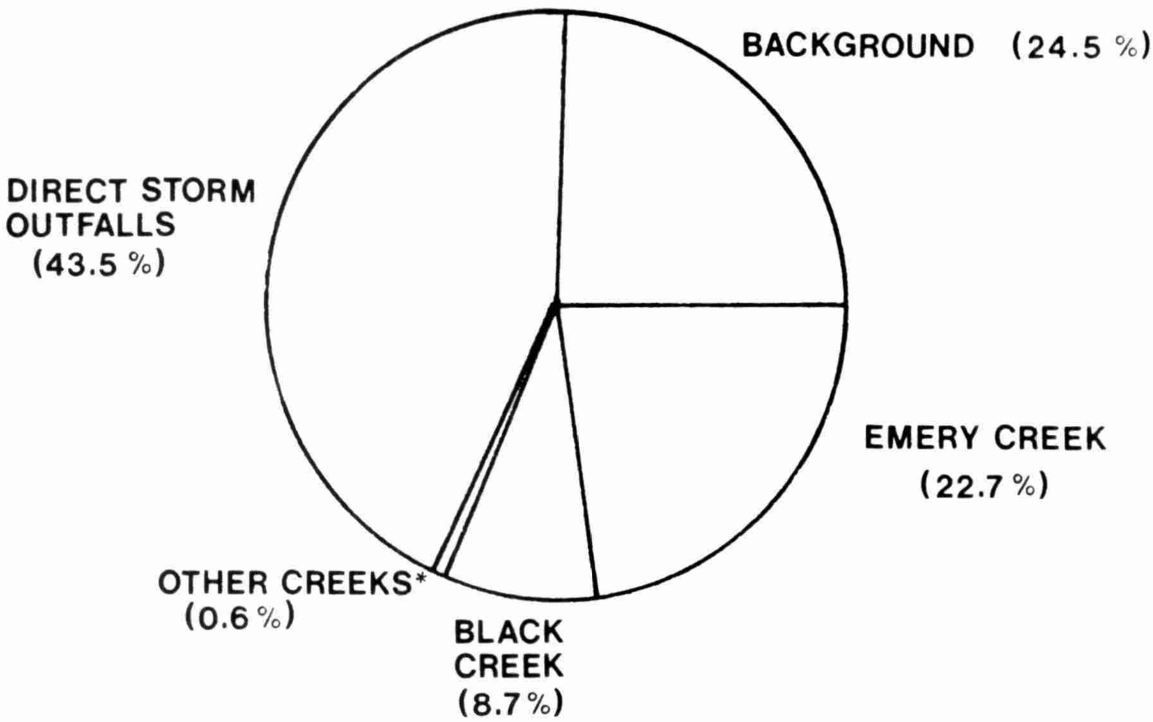
* Dry Weather Data: Metro Works, June - Aug., 1983-1985
Gore & Storrie, fall, 1983

** Dry Weather Data: Metro Works, June - Aug., 1983-1985.

4.2 Existing Trends

Using the mass balance approach, steady-state simulations were generated to approximate the relative sub-watershed contributions of fecal colifom bacteria under existing conditions. Figure 4.1 indicates the distribution during dry weather. The upper Humber contributes about 25% of the dry weather load. Emery Creek and Black Creek are significant dry weather sources, producing about 30% of the load; the contribution by other tributaries is minor. The large contribution by storm sewers discharging directly into the Humber River, particularly the priority outfalls, is significant. The large load percentage associated with these direct storm sewer outfalls indicates the importance of the current program to trace illegal connections.

Flow data and fecal coliform results from the MOE 1985 sanitary survey are outlined in Table 4.2. The background count of 800/100 mL observed at Steeles Avenue fell within the overall range of data (44 to 1300/100 mL) collected by MTRCA and the Metropolitan Toronto Works Department in this area. Fecal Coliform concentrations observed at Steeles Avenue emphasize a PWQO exceedence trend in the upper reaches of the river. This may be due to upstream sewage inputs from; illegal sanitary discharges, inadequately treated sewage in Kleinberg or Woodbridge, scattered urban activities and agricultural operations. These counts may be reduced through programs aimed at reducing livestock and wild animal access to the upper Humber and eliminating sanitary inputs. For the purpose of this study it has been assumed that high counts will continue.



*Other Creeks includes the West Humber River

FIGURE 4.1 : DRY WEATHER FECAL COLIFORM LOADING SOURCES

Table 4.2 - MOE 1985 Sanitary Survey Results

Location	Flow (cms)	FC (#/100 mL)
Humber River @ Steeles Ave.	1.284	800
Rowntree Creek	0.002	220
Emery Creek	0.050	19000
West Humber River	0.017	490
Berry Creek	0.006	430
Weston Creek	0.005	210
Humber Creek	0.035	200
Keelesdale Reservoir*	0.008	400
Silver Creek	0.028	100
Outfall # 17	0.004	120
Black Creek	0.159	2100
Humber River @ Old Mill	1.684	400
Humber River @ Lakeshore	-	1200

* Outfall # 537, Gartner Lee Dry Weather Outfall Survey, TAWMS Technical Report #1, 1983.

Emery Creek and Black Creek are also noted as significant contributors of bacterial pollution. Specifically, Emery Creek and Black Creek account for approximately 30% of the total dry weather load to the Humber River (see Figure 4.1). Dry weather bacterial loads from the other tributaries were 2 to 3 orders of magnitude lower than those from Emery Creek or Black Creek as indicated in Table 4.3. Table 4.4 indicates that both the Emery Creek and the lower Black Creek sewersheds drain highly industrialized catchments. This may be a factor in explaining the high fecal coliform counts observed at the mouths of both Emery and Black Creeks. Berry Creek, Weston Creek and Humber Creek also drain fairly urbanized catchments. Although the MOE fecal coliform guideline was exceeded at the mouths' of these creeks, the fecal coliform concentrations observed were substantially lower than those observed in Emery Creek or Black Creek. It is highly possible that the density and type of land use in the Emery Creek and Black Creek sewersheds play a major role in adversely affecting the creeks. It is noteworthy that in the course of routine field work, during the period April 1985 to August 1985, MOE staff encountered 8 separate spills during 17 field investigations. Of the 8 spills, 6 were observed in the Emery Creek sewershed of which 4 were traced back to specific storm sewer outfalls. One (1) spill was observed on the Black Creek sewershed; it was traced back to a priority outfall. The other spill occurred on the West Humber River. It also originated from a storm sewer. Table 4.5 summarizes these findings.

Table 4.3 - Tributary Loads

Node	Tributary	Load Fecal Coliform (Counts/day x 10^6)	% Load
3	Rowntree Creek	380	0.03
7	Emery Creek	820 800	72.56
8	West Humber River	7 197	0.64
10	Berry Creek	2 229	0.20
13	Weston Creek	907	0.08
16	Humber Creek	6 048	0.53
18	Keelesdale Reservoir*	2 765	0.24
19	Silver Creek	2 419	0.21
20	Black Creek	288 490	25.50

* Outfall #537 Gartner Lee Dry Weather Outfall Survey, TAWMS Technical Report #1, 1983.

Table 4.4 - % Impervious Area of Tributary Drainage Areas

Tributary	Sewershed Reference No.*	% Impervious	FC Counts
Rowntree Creek	3.3.36	26.2	220
Emery Creek	4.3.53	54.8	19,000
West Humber River	3.3.37	22.1	490
Berry Creek Weston Creek	3.3.35	43.9	430
Humber Creek	3.3.51	44.9	200
Silver Creek	3.3.50	24.3	100
Black Creek			
Upper	4.3.33	35.1	2,100
Lower	6.3.32	51.4	

* TAWMS TASK 3, Storm Sanitary and Combined Sewer Mapping and Data Enumeration, Gartner Lee Associates Limited, July, 1983.

TABLE 4.5: Spills Observed by MOE & U of T staff in the Humber River and Black Creek for the Period April, 1985 to August, 1985

Date	Report By	Location	Description of Spill	Response	Comments
Apr 24/85	MOE Staff	Maybank Ave. & Weston Road Source appears to be either outfall #125 or outfall #127. These outfalls drain into Runnymede Tributary which flows into Black Creek.	Brown - creamy substance in sewer pipe. After entering the stream it changed into a foaming white substance.	Contacted Metro works who arranged for samples to be taken.	Charges have been laid by Metro.
Jul 25/85	University of Toronto staff	Humber River downstream of Cooks Creek.	Grayish murky substance in Cooks Creek.	Contacted Central Region, MOE. Requested samples to be taken.	
July 25/85	MOE Staff	Storm sewer #200 located approximately 75m downstream of Albion Road on West Humber River.	Oil in storm water. Oil was well contained in the sewer by debris on the sewer gate. However, the first storm would cause the oil to be flushed into the West Humber River	Contacted Metro Works, Etobicoke and Central Region, MOE. Requested clean-up.	
Jul 30/85	MOE Staff	Cooks Creek	Oily film on water.	Contacted Central Region, MOE.	
Aug 2/85	MOE Staff	Emery Creek, Finch & Weston Road.	Red substance in the water.	Contacted Central Region, MOE	
Aug 22/85	MOE and U of T Staff	Small outfall on Cooks Creek Outfall # 264	White creamy substance	U of T collected samples	High bacteria counts detected.
Aug 22/85	MOE and U of T Staff	2 outfalls on Emery Creek Outfall #502 - Outfall #504 -	Green & grayish colour substance in water. Pink & redish substance in water.	Contacted Central Region, MOE. Requested samples to be taken.	High levels of heavy metals detected in outfall 502.

Note: 1) Outfall numbers referred to above are taken from the Gartner Lee Dry Weather Outfall Survey, TAWMS, TR#1, 1983.

2) Table obtained from the Humber River Water Quality Management Plan.

The Humber River and Black Creek are also adversely affected by priority outfalls discharging directly to the respective watercourses. As of July 1985 the Abatement Committee had identified a total of 52 priority outfalls, outfalls with significant loads of bacteria, discharging directly into the Humber River or its tributaries. Table 4.6 outlines the distribution of priority outfalls within the watershed. The load and percent load from both the priority and non-priority storm sewer outfalls on the Humber River and Black Creek are specified in Table 4.7, along with an indication of the number of priority and non-priority sewers discharging to each watercourse. It is noteworthy that the load from priority outfalls discharging into Black Creek is approximately 64% of that being discharged into the Humber River. The assimilative capacity of Black Creek, however, is much smaller than that of the Humber River as is observed from its present state of deterioration. It is also notable that the load discharged to Black Creek from non-priority outfalls is approximately 5 times greater than the load discharged to the Humber River from non-priority sewers, although the number of non-priority outfalls discharging to both watercourses is approximately equal.

Table 4.8 indicates that of the 18 priority outfalls discharging directly into the Humber River, the majority of the load enters the system in reach C. Specifically, priority outfall #2 (TAWMS Technical Report #1) accounts for about 86% of the total dry weather storm sewer load discharged directly to the Humber River. This outfall has been sampled 32 times as part of the TAWMS storm and combined sewer outfall abatement activities and has a calculated fecal coliform geometric mean density of 104 623 organisms/100 mL.

Table 4.6: Priority Outfall Distribution - Number of Priority Outfalls Discharging Directly to the Humber River or a Tributary

Tributary	# of Priority Outfalls
Humber River	18*
Rowntree Creek	2
Emery Creek	1
Black Creek	30
Humber Creek	1
TOTAL	52

* the number of outfalls discharging directly to the Humber River between Steeles Ave. and Lakeshore Blvd.

Table 4.7: Net Outfall Loads to the Humber River and Black Creek

Humber River	# of	Load (org./day x 10^9)	% Load
Priority sewers discharging directly to the Humber River	18	1544.6	98.0
Non-Priority Sewers	75	31.5	2.0
TOTAL	93	1576.1	

Black Creek	# of	Load (org./day x 10^9)	% Load
Priority sewers discharging directly to Black Creek	30	991.5	86.6
Non-Priority Sewers	78	153.6	13.4
TOTAL	108	1145.1	

Table 4.8: Humber River: Priority Outfall Distribution with respect to Designated Reach Areas

Reach	# of Priority Outfalls	Load from Priority Outfalls (org./day x 10^9)	% Total Outfall Load to the Humber River
H	0	0.0	0.00
E	2	2.3	0.15
F	0	0 0	0.00
E	1	13.5	0.86
D	1	13.1	0.83
C	4	1411.7	89.57
B	7	103.7	6.58
A	3	0.3	0.02
Total # of priority outfalls	18	1544.6	98.00
Total # of non-priority outfalls	75	31.5	2.00

Table 4.9 indicates that of the 30 priority outfalls discharging directly into Black Creek, almost half the priority outfall load enters the tributary in reach L (lower Black Creek), while a little more than 20% enters in reach P (upper Black Creek). The remainder of the load is distributed among the other reaches as indicated in Table 4.9.

In summary, a concentrated effort to eliminate selected priority outfalls in reach B and C should effectuate a major reduction in the storm sewer load to the Humber River. Elimination of priority outfalls on Black Creek (reach L and P) and on Emery Creek should also result in a net reduction of the storm sewer load to the tributaries and hence to the Humber River. Figure 4.2 highlights these priority reaches and the priority tributaries within the watershed.

Table 4.9: Black Creek Priority Outfall Distribution with respect to Designated Reach Areas

Reach	# of Priority Outfalls	Load from Priority Outfalls (org./day x 10^9)	% Total Outfall Load To Black Creek
Q	2	23.8	2.08
P	4	237.8	20.77
O	3	23.2	2.03
N	4	58.7	5.13
M	3	94.5	8.25
L	14	553.5	48.34
Total # of priority outfalls	30	991.5	86.60
Total # of non-priority	78	153.6	13.40

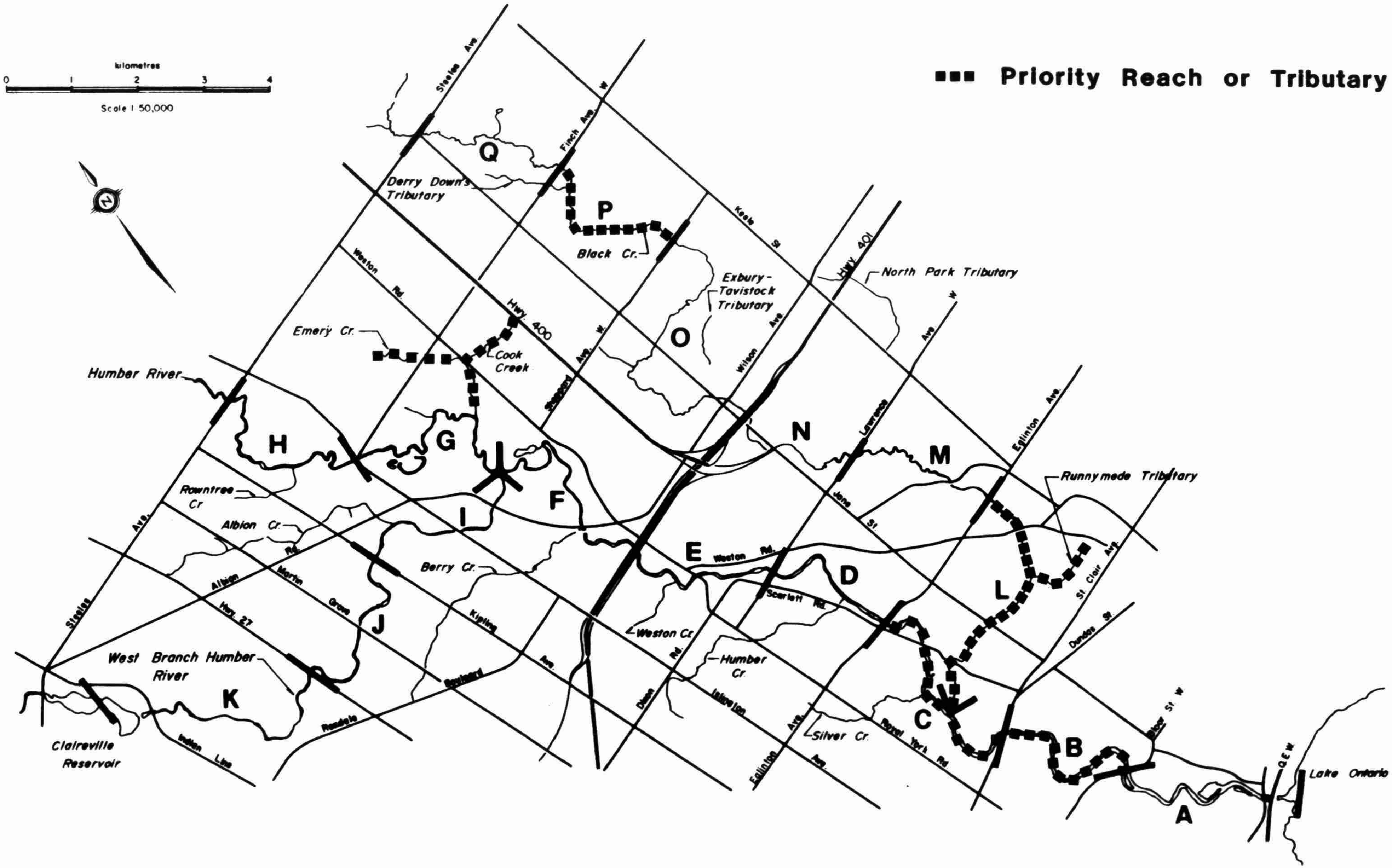


FIGURE 4.2 PRIORITY REACHES AND TRIBUTARIES

4.3 Scenario Testing

Being a non-conservative parameter, concentrations of fecal indicator bacteria decrease as they move downstream from their source, because of natural die-off, dilution, predation and sedimentation. The selection of a single location for assessing the impacts of control measures will therefore introduce a bias, emphasizing the importance of controls close to the source and downgrading the control's importance as one moves farther away from the source. For example, if the effectiveness of controls is only assessed in terms of bacterial counts at the mouth of the Humber, then controls on Black Creek will be important, while those near Steeles Avenue will be less significant. This would mask the importance of upstream controls by giving no weight to reductions in bacteria counts in the upper reaches. As a result, it is important to examine bacterial contamination on the basis of in-stream reductions at a number of locations.

During dry weather major bacterial pollution sources comprise bird and animal excretions and storm sewer discharges. Direct contamination by non-domesticated birds and animals remains largely uncontrollable, however, the majority of the dry weather bacterial contributions from storm sewers can be eliminated because of the relatively small number of priority outfalls. Elimination can be accomplished through either tracing and disconnecting illegal connections, or through intercepting the dry weather flows for diversion to the sanitary system. In either case, fecal pollution is prevented from reaching the watercourse. It is recognized, that tracing and disconnecting illegal connections may not be completely effective and may require new methods of detection.

Intercepting all priority outfalls may be too expensive or infeasible in certain instances. Consideration must, therefore, be given to treating the fecal pollution once it has been released to the stream. This option would involve ultraviolet disinfection of dry weather flows at selected locations, usually near the mouth of a tributary stream. The disinfection alternative is highly effective but it will only benefit the main Humber River and not the tributaries. For this reason it should be considered as an interim measure only.

It can be concluded that under dry weather conditions the primary control emphasis must be the elimination of priority storm sewer outfalls, either through tracing and disconnection or interception. At two locations, Emery Creek and Black Creek, disinfection could be used as an alternative to the elimination of priority storm outfalls on the tributaries. Disinfection at the downstream end of each creek would not result in improvements to the water quality within the creeks. Therefore, it cannot be adequately substituted in place of complete elimination of major bacterial sources. Disinfection is still considered a useful interim measure for tributaries with high bacterial loads as it can produce the highest quality effluent in terms of bacteria.

The feasible alternatives were quantitatively assessed using the first order decay model. Bacterial inputs to the river were reduced in accordance with control option efficiencies. Given the various assumptions and limitations of the computational procedure, the model is useful in comparing the relative impacts of the proposed control options.

4.4 Findings

Figure 4.3a presents the simulated instream fecal coliform bacteria concentrations under existing dry weather conditions. As previously mentioned a count of 800/100 mL was observed at Steeles Avenue, the beginning of the urban Humber. This value fell within the overall range of data (44 to 1300/100 mL) collected by MTRCA and the Metropolitan Toronto Works Department at this location. Moving downstream from Steeles Avenue there is a general decline in fecal coliform concentrations as a result of die-off until the confluence with Emery Creek is reached. This creek is a major source of fecal pollution and its input raises instream fecal coliform concentrations to about 1100/100 mL. After Emery Creek, a decline in concentration is again manifest. Natural disappearance processes reduces concentrations to about 300/100 mL just upsteam of the confluence with Black Creek. At the confluence, the impact of Black Creek raises the concentration to approximately 450/100 mL. Just downstream of the Black Creek confluence, inputs from several priority sewers, particularly outfall #2, raises the instream fecal coliform concentration abruptly to about 1300/100 mL. Limited disappearance below the confluence area reduces the concentrations to about 900/100 mL as the Humber River enters the lake.

Figure 4.3b indicates the impact of eliminating priority outfalls on Emery Creek and Black Creek or, alternatively, disinfecting their effluents. Each alternative has a significant impact on the Humber River, with the disinfection option being more effective because it acts on all sources of bacteria rather than just the priority outfalls. Priority outfall discharges, directly into the Humber River and downstream of the confluence with Black Creek, are sufficient enough however to raise concentrations to about 1000/100 ml. Since the provision of disinfection at each outfall is not practical, it is clear that elimination of these priority outfalls, through either tracing and disconnecting or collection and treatment, is necessary if bacterial contamination of the lower Humber and the lake is to be reduced in dry weather.

Figure 4.3c outlines the impact of eliminating all priority outfalls. The concentrations of fecal coliform bacteria are reduced to approximately the PWQO (100/100 ml) in the lower reaches approaching the lake. Bacterial concentrations remain above the PWQO in the upper reaches because of the impacts of rural inputs. It can be concluded however that a significant overall improvement is achievable during dry weather conditions.

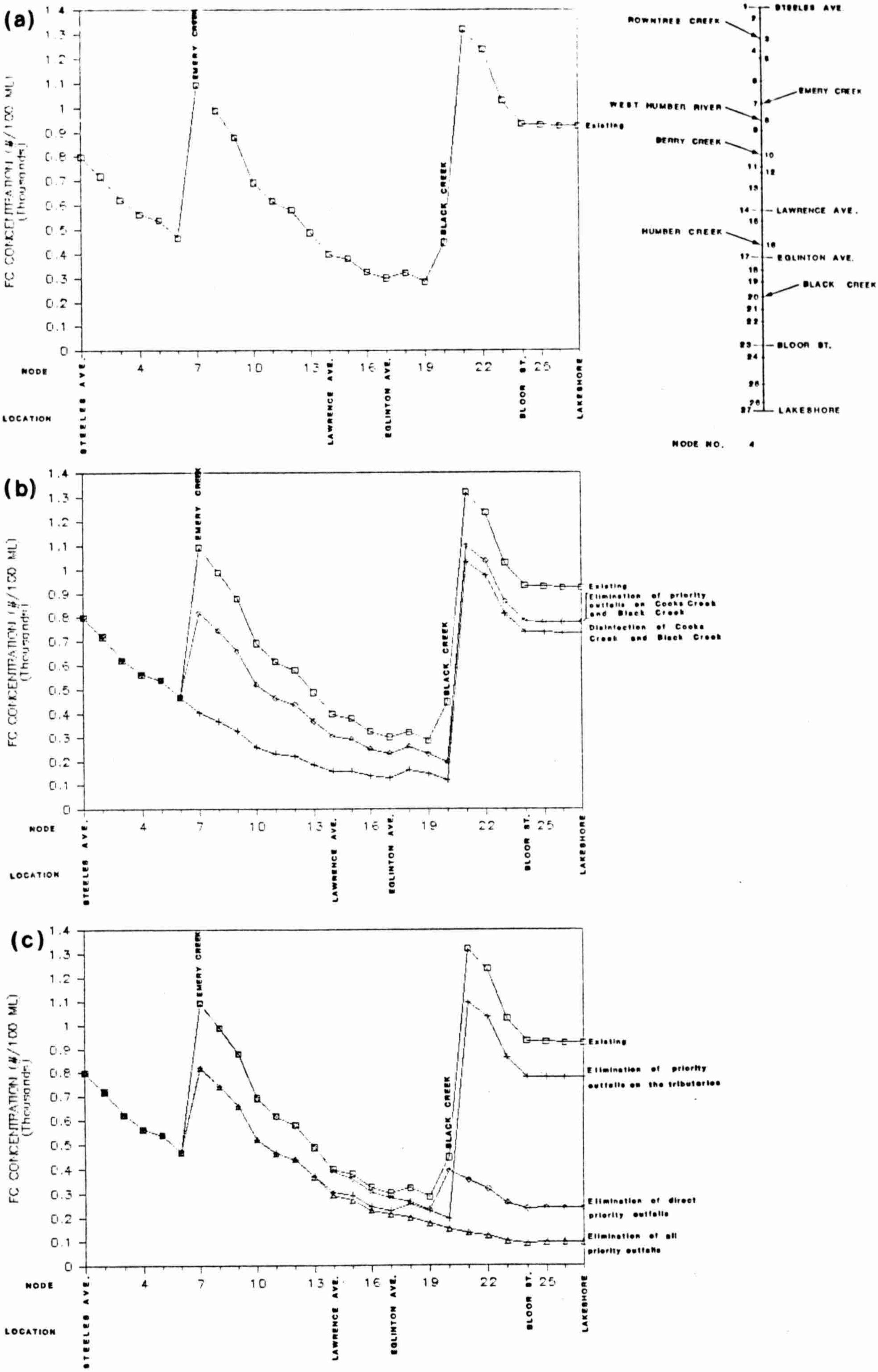


FIGURE 4.3: HUMBER RIVER SCENARIO TESTING - DRY WEATHER

It should be noted that during the summer period, when recreational use of the Humber River is at its highest, dry weather conditions occur approximately 85% of the time. Dry weather controls would be expected to improve the bacterial water quality for this major time period. Dry weather controls would also have an impact on wet weather conditions, since deposited pollutant loads, normally subject to scour during wet events, would be reduced by dry weather controls.

5.0 WET WEATHER ANALYSIS

5.1 Data Set and Model Calibration

Simulation of fecal coliform levels during wet weather conditions is substantially more difficult than during dry weather because of the effects of differences in the timing of basin response, rainfall variations, routing of flows and the duration of impacts. Previous studies have attempted detailed simulations with limited success (Rideau River Stormwater Management Study, MOE, 1983). For the purposes of this study, a relatively crude method, utilizing die-off and assuming steady state conditions at various points during a typical storm event, was used. Additional data would be required before a more sophisticated modelling approach would be warranted.

The event simulated started at 7 pm on June 10, 1979. It consisted of a four hour rainfall, with the maximum rainfall intensity ranging from 15.6 to 26.2 mm/hr across the basin. Combined sewers in the Black Creek sub-basin overflowed for 2 hours, discharging an average of 11.0 m^3/s in the first hour and 1.1 m^3/s in the second as calculated by the urban drainage model SWMM. Flows at sequential node points were incremented according to calibrated HSP-F results for this event. A constant fecal coliform level of 24000/100 mL was assumed for discharging storm sewers during the event (Rideau River Stormwater Management Study, MOE 1983). It was assumed that storm sewer fecal coliform levels returned to dry weather conditions (measured by Gartner Lee, fall 1982) by hour 10 of the event.

Using the mass balance approach, fecal coliform densities were calculated at each node for hour 1, 3 and 10 of the storm. No actual observed fecal coliform levels were available for the event to calibrate the wet weather model. However, based on dry weather results, the model was assumed accurate enough to relatively assess control option impacts by comparing respective simulation results to the existing case. In general, further studies with respect to wet weather processes would be an asset for future implementation analyses.

5.2 Existing Trends

The causes of the contaminant loadings and the means available for controlling fecal pollution are quite different during wet weather events due to the large number of sources and the magnitude of flows involved in wet weather. Existing trends for wet weather conditions cannot be summarized as easily as for dry weather conditions. It should also be noted that the uniqueness of each wet event with respect to total rainfall, rainfall intensity, rainfall variation and rainfall duration across the watershed can hinder the analysis if the determination of an annual wet weather load is required. The June 10, 1979 storm was selected for simulation purposes since it represented average storm conditions for which the entire watershed responsed. In other words, the storm was selected due to its average rainfall intensity and fairly uniform rainfall distribution across the entire watershed.

In general it can be concluded that under wet weather conditions the distribution of the loading shifts thus emphasizing urban sources. The upper Humber becomes a comparatively minor source, due to the large increase in urban loads. The major urban bacterial sources are the numerous storm sewer outfalls, combined sewer overflows and certain tributary loads. The main tributaries of concern discharging substantial loads are Emery Creek and Black Creek. Black Creek is of particular concern due to the presence of several combined sewer outfall points and its proximity to the lake. CSO, although small in terms of volume compared to storm sewer discharge, is considered to be the most serious source; its high fecal coliform density results in a greater potential for the presence and discharge of specific human pathogens into the environment.

During wet weather instead of 52 dry weather priority outfalls contributing high bacteria counts, virtually all outfalls become potent sources of bacteria, as each catchment is flushed of its accumulated load. The elimination of storm sewer sources is impractical, however, due to the magnitude of the total flow from the large number of storm sewers discharging directly to the watercourses. Similarly, disinfection of natural tributary discharges is not possible because of the magnitude of the peak flows. Interception of combined sewer overflows on the other hand is a practical means of reducing bacterial loading during storm events because of the limited number of overflow points. The prevention of the buildup of fecal pollution on the urban catchment is possible through the enforcement of regulations such as dog and litter control bylaws. Regulation is a useful approach from both a water quality and an aesthetic point of view, although it is not

expected to be sufficient on its own. The only other practical means of reducing bacterial loadings to the river is through the retention of stormwater in a stormwater pond. These facilities would capture runoff and retain it for periods of one to two days, to allow time for the natural die-off and sedimentation of bacteria. A maintenance program would be implemented to remove the build-up of sediment. The retention facilities could be augmented by disinfection units to increase the removal efficiency of bacterial loadings.

5.3 Scenario Testing

In general, under wet weather conditions the major urban bacterial sources are the numerous storm sewer outfalls and the combined sewer overflows. These wet weather loadings, however, are very difficult to control due to the number of sources and the magnitude of flow involved. This results in relatively few alternatives for the control of bacteria in wet weather. The only alternatives that can be quantitatively assessed are the elimination of CSO to reduce the potential for discharge of specific human pathogens and the use of stormwater retention ponds on selected tributaries. For the purposes of simulation, ponds have been assumed to be technically feasible on Emery Creek, Berry Creek and Humber Creek. Their level of efficiency has been simulated as providing an 80% reduction in the total wet weather fecal coliform load. Although it is recognized that a greater degree of tributary control would be necessary to affect a significant reduction in fecal coliform load, simulation of ponds at these locations is able to demonstrate the type of impact expected from retention facilities.

Figure 5.1 demonstrates the effect of control option implementation on hourly fecal coliform loads at two stations, Bloor Street and Eglinton Avenue, each on the main Humber River. Loads are shown for hours 1, 3 and 10 of the storm event.

5.4 Findings

It is evident from Figure 5.1 that the elimination of CSO would have a major impact on initial fecal coliform loads at Bloor Street, reducing the hour 1 steady state load by 84%. By hour 3, however, the impact of CSO elimination has dropped to zero. This is typical of most rainfall events because overflows usually occur quickly and are of relatively short duration. CSO elimination has no impact at Eglinton Avenue, because the overflow points are located in the southern portion of the Black Creek sub-basin.

The three retention ponds are all located on tributaries above Eglinton Avenue. A nominal reduction in the fecal coliform load is noticable during hour 1 at both Eglinton Avenue and Bloor Street. By hour 3, the impact of ponds has reached a maximum, producing a load reduction of about 6%. The small amount of load reduction is the result of the limited area controlled and the fact that although the pond effluent volumes have been reduced, there has been insufficient time for substantial die-off. By the tenth hour, runoff from the urban areas has ceased and the loading noted is the result of inputs from the upper Humber. The ponds do not have much impact by this time, although continued discharge produces a very slight increase in fecal coliform loading.

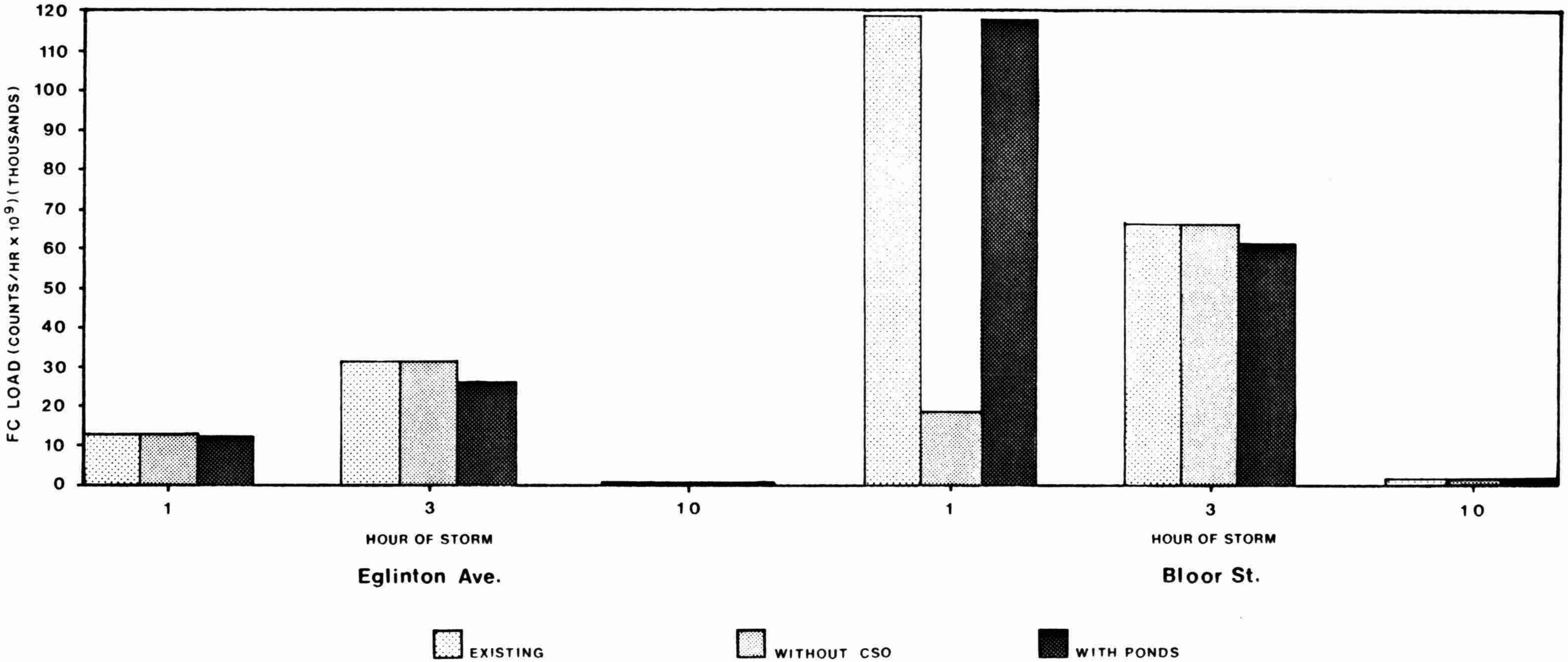


FIGURE 5.1: HUMBER RIVER SCENARIO TESTING – WET WEATHER

It should be emphasized at this point that the lack of available data for wet weather conditions has effectually hindered the analysis. The main conclusion drawn from the wet weather analysis is that the load reductions effected by the control options will not be sufficient to bring instream concentrations down to levels approaching the PWQO of 100/100 mL. Although the possibility of attaining the PWQO in wet weather conditions is low, wet weather controls can be useful in improving the overall water quality. Improvements incurred during wet weather conditons will also have a 'carry-over impact' on dry weather conditons evidenced by a reduced potential for sediment contamination, specifically with respect to the harbouring of specific human pathogens and improved aesthetics.

6.0 LEVEL 1 ANALYSIS

In the interests of examining seasonal factors and of comparing urban and rural pollutant problems, a study of PWQO violations and fecal coliform loadings was carried out for the entire watershed.

The study area was divided into 5 sub-watersheds; Claireville, Pine Grove, Elder Mills, Black Creek and the lower Humber, as indicated in Figure 6.1. The delineation of the aforementioned sub-watersheds was influenced by the location of Provincial Water Quality Monitoring Network (PWQMN) stations and Water Survey of Canada (WSC) streamflow gauges. The (PWQMN) stations and WSC streamflow gauges chosen to represent each sub-watershed are outlined in Table 6.1, station and gauge locations are also indicated on Figure 6.1.

Specific objectives of this level 1 analysis (1) are:

1) identify violations of the PWQO on a sub-watershed basis

2) generate fecal coliform loadings on a sub-watershed basis

3) identify existing and potential problems on a sub-watershed basis and on an urban versus rural land use basis.

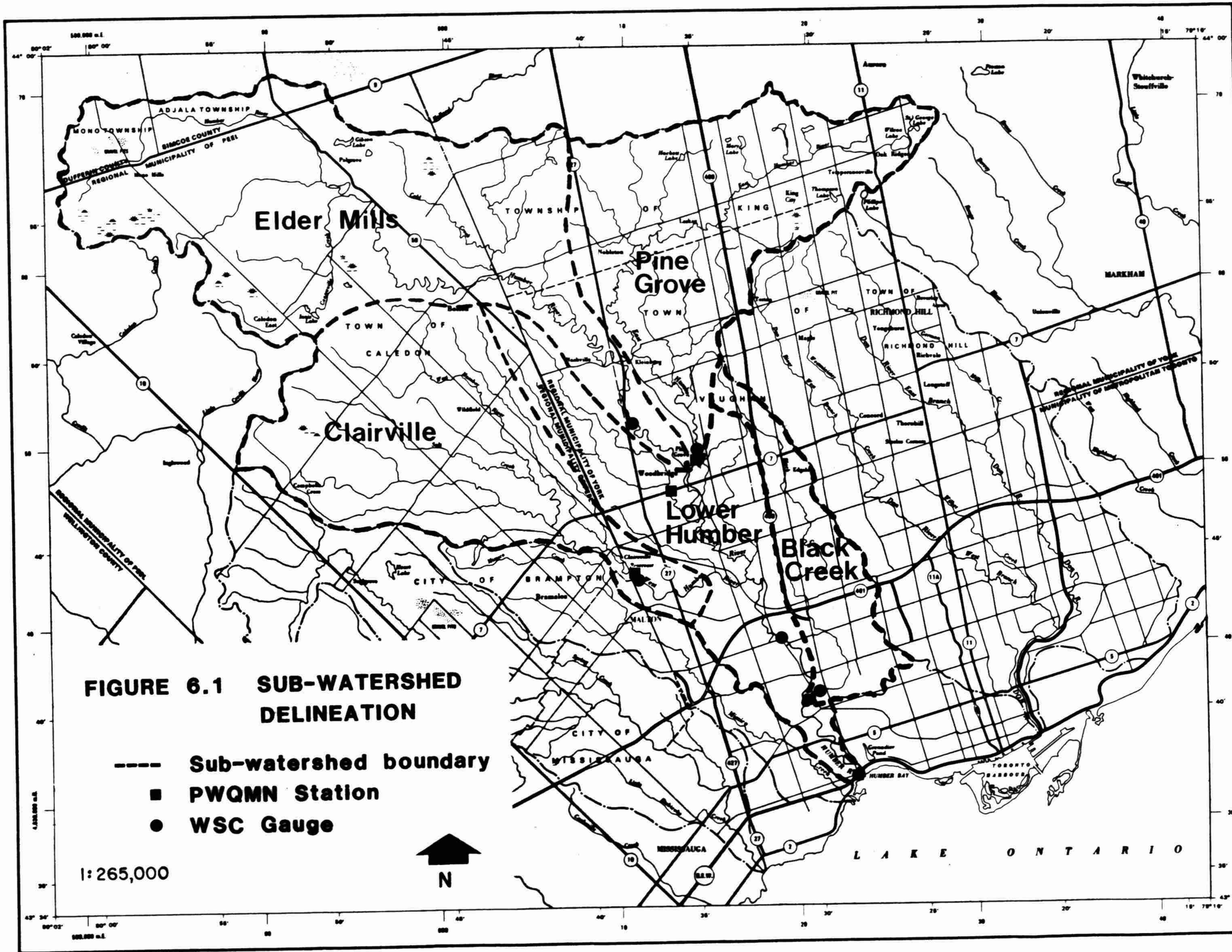


FIGURE 6.1 SUB-WATERSHED DELINEATION

Table 6.1 Sub-Watershed Areas and PWQMN/WSC Station Allocations

SUB-WATERSHED	AREA (km^2)	PWQMN STATION NAME AND NUMBER	WSC STREAMFLOW STATION NUMBER	REMARKS
Claireville	194	West Humber River @ Claireville Dam Outlet 06-0083-002-02	02HC034	Period of record ended April 1984 for PWQMN station
Elder Mills	303	Humber River @ York-Peel County Line 06-0083-005-02	02HC025	
Pine Grove	197	East Humber River @ Pine Grove Road 06-0083-004-02	02HC009	
Black Creek	69	Black Creek @ Scarlett Road, Toronto 06-0083-012-02	02HC027	
Lower Humber	138	Humber River @ Lakeshore Rd., Toronto 06-0083-001-02	02HC003	

The time period selected for analysis began April 1, 1979 and extended to March 31, 1980. For simulation purposes the seasons were divided as follows:

Spring	April 1, 1979 to May 20, 1979
Summer	May 21, 1979 to Sept. 3, 1979
	(i.e. Victoria Day to Labour Day)
Fall	Sept. 4, 1979 to Dec. 31, 1979
Winter	Jan. 1, 1980 to March 31, 1980.

Concentration time series (1) and loads were calculated for that time period. The number of violations for each sub-watershed was determined from the generated times series output. Seasonal and annual loads were summed for their respective time periods. Table 6.2 and 6.3 present the results of the violation and loading analysis.

Referring to Table 6.2 it is observed that, based on historical data, Black Creek has a very high probability of violation and the Humber River at Lakeshore (Lower Humber) has a 100% probability of violation. The high occurrence of violations may be attributed to the urbanized nature of some sources which include combined sewer overflows, storm sewer overflows and industrial inputs. Comparing the % violations and fecal coliform loadings in Table 6.2 and 6.3 for the urban and rural sub-watersheds, it is apparent that urban sources contribute more in terms of loading and % violation than the rural sub-watersheds. This emphasizes the need to concentrate efforts on urban controls. The east branch (Pine Grove) and west branch (Claireville) of the Humber River

Table 6.2: Violation Analysis - Results

Season	# of Days in Season	# of Violations (% Violations)				
		Claireville	Pine Grove	Elder Mills	Black Creek	Lower Humber
Spring	50	21 (42%)	12 (24%)	41 (82%)	48 (96%)	50 (100%)
Summer	106	18 (17%)	4 (4%)	70 (66%)	104 (98%)	106 (100%)
Fall	119	18 (15%)	23 (19%)	58 (49%)	118 (99%)	119 (100%)
Winter	91	17 (19%)	17 (19%)	39 (43%)	88 (97%)	91 (100%)
TOTAL	366	74 (20%)	56 (15%)	208 (57%)	358 (98%)	366 (100%)

Table 6.3: Loading Analysis - Results

Season	# of Days in Season	Loading - org./day x 10^6				
		Claireville	Pine Grove	Elder Mills	Black Creek	Lower Humber
Spring	50	53 084	35 128	42 097	471 554	641 233
Summer	106	958	1 937	14 861	180 728	180 383
Fall	119	66 431	42 417	32 289	1 514 182	2 153 201
Winter	91	47 466	69 140	37 157	551 962	1 834 399
TOTAL	366	167 939	148 622	126 404	2 718 426	4 809 216

generate approximately equal amounts of fecal pollution as evidenced by their relatively equal loading and % violations. The slight differences in loadings and % violations may be due to differences in soil type and land use and impacts from the Claireville dam. The fecal coliform load from the upper Humber (Elder Mills) is lower than its tributary branches, however, the % violations is significantly higher. This may suggest that the Bolton or Kleinburg water pollution control plant does impact the main upper Humber River bacteriological water quality. The upper Humber River Study (TAWMS, TR#8, 1986) may pinpoint other sources contributing to the pollutant load such as agricultural inputs or storm sewer discharges.

Table 6.3 also indicates that the summer season contributes only a minor portion of the total annual fecal pollution load. This may be due to the fact that dry weather conditions prevail approximately 85% of the time in the summer. Lower flows and higher temperatures result in increased disappearance of fecal coliform although violations of the PWQO still occur.

7.0 SUMMARY

In terms of bacterial contamination there is both a dry weather and a wet weather problem. Tables 7.1 and 7.2 summarize the dry and wet weather simulation results respectively.

Referring to Table 7.1, dry weather contamination can best be ameliorated through a combination of disinfection of Emery Creek and Black Creek effluents and the elimination of known priority outfalls. The elimination of the dry weather sources is critical to the reduction of fecal coliform counts in the lower portion of the basin. The level 1 analysis emphasizes that although the summer season does not contribute a large runoff pollutant load to the Humber River, a concentrated effort must be made to control dry weather sources so that the PWQO can be met during the summer season, which is the focus of concern for body contact criteria.

In general the maximum possible reduction in the pollutant load to the Humber River can be achieved through the implementation of all possible controls. However, it is unlikely that all of the controls in each sewershed will be implemented. Some factors which may impact implementability are costs, public reaction and land availability. It should be noted at this time that due to the assumptions and limitations of the dry weather model, actual observed water quality after the implementation of a control may differ from the simulated results presented in this report.

TABLE 7.1 : DRY WEATHER SIMULATION RESULTS - Bacteria

Objective	Alternative	Observed Instream Count (#/100 ml)	Simulated Instream Count (#/100 ml)	Location	Impact Area
				Node	
To reduce the bacterial load	1) Eliminate	1094	820	7 - Emery Creek conference	Humber River from Emery
to the Humber River from	priority outfalls	923	897	27 - Lakeshore Blvd	Creek confluence to Black
Emery Creek for water	on Emery Creek				Creek confluence
quality enhancement in the				Node	
upper reaches of the urban	2) UV Disinfection	1094	403	7 - Emery Creek conference	
river	of Emery Creek	923	858	27 - Lakeshore Blvd	
				Node	
To reduce the bacterial load	1) Eliminate	432	196	20 - Black Creek confluence	
to the Humber River from	priority outfalls	932	786	27 - Lakeshore Blvd.	Creek confluence area
Black Creek for water quality	on Black Creek				due to inputs from
enhancement in the lower				Node	priority outfalls
reaches of the river and	2) UV disinfection	432	120	20 - Black Creek confluence	immediately downstream
Humber Bay	of Black Creek	923	742	27 - Lakeshore Blvd	of Black Creek
To reduce the bacterial load	1) Eliminate		i ii	Node	Mainly from the Black
to the Humber River from the	priority outfalls	432	410 389	20 - Black Creek confluence	Creek confluence to
direct storm sewer outfalls	discharging	1027	641 255	23 - Old Mill	Lakeshore Blvd. with
for water quality enhance-	directly into the	929	580 231	24 - Bloor St.	minor impacts in the
ment throughout the river	Humber River	923	579 234	27 - Lakeshore Blvd.	upper reaches
reaches (Note: Priority	i) reduce priority				
direct storm sewer loadings	loadings by 50%				
tend to be concentrated	ii) reduce priority				
betweem Scarlett Road and	loadings by 100%				
Bloor St. - see figure 2)					
			i ii	Node	
To reduce bacterial loadings	1) MTRCA policy -	800	400 100	1 - Humber River at Steeles Ave.	Steeles Ave. to Albion
from the Upper Humber	reduce background	1094	900 755	7 - Emery Creek Confluence	Rd.
Watershed for water quality	counts to	693	571 480	10 - Berry Creek confluence	
enhancement in the upper	i) 400/100 mL				
reaches of the river	ii) 100/100 mL				
				Node	
To reduce the total urban	1) Elimination of	800	800	1 - Humber River at Steeles Ave.	Humber River from Emery
bacterial load to the	priority outfalls	1094	818	7 - Emery Creek confluence	Creek confluence to the
Humber River (cumulative	discharging directly	693	520	10 - Berry Creek confluence	Lakeshore
effect of all dry weather	to the Humber River	397	291	14 - Lawrence Ave.	
control options)	and the elimination	300	215	17 - Eglinton Ave.	
	of priority outfalls	432	154	20 - Black Creek Confluence	
	on the tributaries	923	98	27 - Lakeshore Blvd.	
				Node	
	2) Elimination of	800	800	1 - Humber River at Steeles Ave.	Humber River from Emery
	priority outfalls	1094	401	7 - Emery Creek confluence	Creek confluence to the
	discharging directly	693	258	10 - Berry Creek confluence	Lakeshore
	to the Humber River	397	147	14 - Lawrence Ave.	
	and UV disinfection	300	107	17 - Eglinton Ave.	
	of Emery Creek and	446	75	20 - Black Creek Confluence	
	Black Creek	926	52	27 - Lakeshore Blvd.	

TABLE 7.2: WET WEATHER SIMULATION RESULTS - Bacteria

Objective	Alternative	Hour of Storm	STA.6 - Eglinton Ave. Existing Instream Count (#/100 ml)	STA.6 - Eglinton Ave. Simulated Instream Count (#/100 ml)	STA.3 - Bloor St. Existing Instream Count (#/100 ml)	STA.3 - Bloor St. Proposed Instream Count (#/100 ml)	Benefits
To reduce the potential for the presence of specific pathogens of human origin.	Eliminate combined sewer overflow from Black Creek	1 3 10	17188 18650 2147	17188 18650 2147	80772 19994 3288	17125 19994 3288	Reduced risk to the user of contracting a disease due to the reduced potential for the presence of specific human pathogens. Reduced industrial waste loadings. Reduced sediment contamination (which reduces the potential for future water column contamination due to resuspended sediments). Improved aesthetics.
To reduce the bacterial load from tributary reaches for water quality enhancement in the upper reaches of the river.	Implementation of retention ponds on Emery Creek, Berry Creek and Humber Creek.	1 3 10	17188 18650 2147	16648 17848 2253	80772 19994 3288	81641 19818 3316	Reduced metals load. Various efficiencies for bacteria removal (Rideau River Study). Additional implementation of an UV disinfection unit on the effluent weir would reduce bacterial load during dry weather. Reduced sediment contamination.
Dog and litter control.	Improved enforcement of by-laws.		Approximately 20% decrease of in-stream fecal coliform densities (Rideau River Study)				Reduced runoff bacterial loadings. Improved aesthetics. Contributes to the reduction in potential for pathogen input.

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Referring to Table 7.2 it can be concluded that wet weather bacterial contamination cannot be sufficiently controlled, using the options considered, to reduce the fecal coliform levels to the PWQO. Mass loading of bacteria can be reduced however, by eliminating CSO and priority outfalls. The impact of these controls is short-lived in terms of in-stream bacterial counts; masses of bacteria are flushed from uncontrolled areas directly into the river during wet events, by-passing these controls. The simulated implementation of stormwater ponds resulted in a small reduction in total fecal coliform loading. It was concluded, however, that ponds were not sufficiently effective to recommend implementation from a bacterial standpoint alone. On the other hand, ponds were found to be the most effective means of reducing heavy metals PWQO violations. Therefore, the design of the facilities implemented for heavy metal control should include a means to reduce the total bacterial load discharged to the river. This can be achieved by allowing sufficient retention time to provide adequate bacterial die-off or by disinfecting the effluent with ultraviolet light.

Previous studies have suggested that improved enforcement of dog and litter bylaws may also yield a 20% reduction in total fecal coliform loadings (Rideau River Stormwater Management Study, MOE 1983). It should be stressed that a crude method, based on little available data, was used to analyse wet weather conditons. Further studies investigating wet weather processes would be an asset to future implementation analyses.

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